HIGH- AND LOW-Btu GAS FROM MONTANA SUBBITUMINOUS COAL

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INTRODUCTION

Two coal gasification processes are under development at IGT. The HYGAS® Process has been developed for high-Btu gas (SNG) from coal; the U-GAS® Process, a much simpler system, has been developed for low-Btu gas. This paper describes the application of these gasifiers for different objectives and compares process and economic characteristics. HYGAS and U-GAS reactor systems are compared for the manufacture of pipeline gas, and the U-GAS Process is analyzed as an advantageous source of low-Btu gas. Three process designs and their economics for manufacturing a nominal amount of 240 billion Btu/day of product gas are discussed. The designs are based on the conversion of Montana subbituminous coal, whose analysis is given in Table 1. Because the coal is nonagglomerating, pretreatment is not required.

Table 1. MONTANA SUBBITUMINOUS COAL

Proximate Analysis	Weight Percent
Moisture	22.0
Volatile Matter	29.4
Fixed Carbon	42.6
Ash	6.0
Total	100.0
Ultimate Analysis (Dry)	
Carbon	67.70
Hydrogen	4.61
Nitrogen	0.85
Oxygen	18.46
Sulfur	0.66
Ash	7.72
Total	100.00
Dry Heating Value, Btu/lb	11,290

PROCESS DESIGNS FOR PIPELINE GAS (HIGH-Btu GAS)

Two process designs for the manufacture of 242 billion Btu/day of SNG at 1000 psig from coal have been made: one hased on the HYGAS Process and a similar design utilizing the U-GAS Process. The capacity was set by an existing design based on the HYGAS Process. A comparison of the two processes will show any economic benefit derived from the use of the more complex and costly HYGAS reactor in contrast to the simpler U-GAS reactor in the manufacture of pipeline gas from coal.

Comparison of the HYGAS and U-GAS Reactors

The HYGAS reactor (hydrogasifier) is designed to maximize direct methane formation by the reaction

$$\text{Coal} + 2H_2 \rightarrow CH_4. \qquad 1)$$

This reaction supplies heat for the endothermic reaction also occurring in the hydrogasifier:

$$\text{Coal} + H_2O \rightarrow CO + H_2. \qquad 2)$$

High pressure in the reactor, 1165 psig in this design, favors the formation of methane.

Process coal at a rate of 15,996 tons/day is dried to 10% moisture and simultaneously ground to below 8 mesh with a maximum of 15% below 100 mesh. The prepared coal is pneumatically conveyed to the slurry preparation section, and a 50% water slurry is pumped to the hydrogasifier. A fluidized-bed dryer is located at the top of the vessel, where the slurry water is vaporized in contact with the hot reactor effluent gases.

The reactor coal feed passes through three zones of conversion: 1) a low-temperature (1000°F) transport reactor, where the coal is devolatilized and rapid-rate conversion to methane enriches the product gas; 2) the main fluidized bed at 1700°F, where most of the methane is formed; and 3) the steam-oxygen gasification zone at 1850°F, where synthesis gas is generated from the hydrogasifier char according to the endothermic steam decomposition reaction

$$\text{Char} + H_2O \rightarrow CO + H_2. \qquad 3)$$

Heat is supplied by partial combustion of the char with oxygen:

$$C + O_2 \rightarrow CO_2. \qquad 4)$$

Further generation of hydrogen occurs in zone 2, where the exothermic methane formation reaction supplies heat for the steam decomposition reaction (Reactions 1 and 2).

The U-GAS reactor is a single-stage fluidized-bed gasifier operating at 1900°F and 335 psig. The reactor is not primarily designed to make methane. To promote methane formation, where SNG is the desired end product, 18,400 tons/day of coal is fed into the upper portion of the gasifier onto the fluidized bed. The countercurrent flow of hot gases and coal devolatilizes the coal, and some methane is formed. Reactions 2 and 4 are the major reactions taking place in this system. A lockhopper coal feed system, which is used commercially at this relatively low pressure level, is used to feed the coal. Further operating details of the U-GAS system are discussed in the section on low-Btu gas.

Raw gas compositions from the two reactors are compared in Table 2. The total moles per hour is the requirement for 242 billion Btu/day of product gas.

Table 2. COMPOSITION OF RAW GAS FROM GASIFIERS

	HYGAS Hydrogasifier Effluent	U-GAS Raw Gas
	mol %	
CO	20.13	34.18
CO_2	18.65	13.30
H_2	23.68	29.52
H_2O	22.68	17.44
CH_4	12.86	4.84
C_2H_6	0.99	--
NH_3	0.34	--
H_2S	0.19	0.20
N_2 + Ar	0.18	0.52
B-T-X	0.30	--
	100.00	100.00
Total mol/hr	103,288	126,576

In addition to coal raw material, generation of these gases requires steam and oxygen. The HYGAS reactor requires 1,003,130 lb/hr of steam at 1200 psig and 1050°F, plus 2999 tons/day of 98% oxygen. The U-GAS reactor requires 670,320 lb/hr of steam at 385 psig and 800°F, plus 7986 tons/day of oxygen.

The Manufacture of Pipeline Gas

The raw gases from both reactors require upgrading to pipeline-gas quality. For the HYGAS plant, the required steps are shown in the flow diagram of Figure 1, and the compositions of the process flow streams are given in Table 3. Figure 2 and Table 4 give similar information for the U-GAS plant.

SNG by HYGAS

The effluent gas is cooled by waste heat recovery and cleaned in a venturi scrubber to remove small particles carried over from the hydrogasifier. The gas is sent to a CO conversion reactor where the H_2/CO ratio is raised to 3.2 or 3.3 in preparation for methanation. The catalyst is an oil- and sulfur-resistant, high-temperature CO conversion catalyst. Steam for this reaction is supplied by vaporized slurry feedwater present in the raw gas.

The B-T-X formed in the hydrogasifier is recovered as a valuable by-product after CO conversion. Oil scrubbing and activated carbon are used for this operation. Large amounts of CO_2 and H_2S must be removed from the gas during the upgrading to pipeline gas quality. This is done by hot carbonate scrubbing; acid gases leaving this section are sent to a Stretford unit for sulfur recovery. Final traces of H_2S are removed by activated carbon and zinc oxide beds.

Table 3. PROCESS FLOW STREAMS FOR A NOMINAL 240 X 10^9 Btu/DAY HIGH-Btu GAS PLANT BY THE HYGAS PROCESS FROM MONTANA SUBBITUMINOUS COAL

Stream Name	Hydrogasifier Effluent		Slurry Water Vaporizer Effluent		CO Shift Feed		B-T-X Recovery Feed		Hot K_2CO_3 Feed		Methanation Feed		Pipeline Gas	
Stream No.	1		2		3		4		5		6		7	
Temperature, °F	1000		600		483		125		125		125		100	
Pressure, psig	1165		1155		1145		1110		1100		1075		1000	
Components	mol %	mol/hr	mol %	mol/hr	mol %	mol/hr	mol %	mol/hr	mol %	mol/hr	mol %	mol/hr	mol %	mol/hr
CO	20.13	20,793	12.91	20,793	13.03	20,793	12.03	10,514	12.06	10,505	17.45	10,477	0.10	28
CO_2	18.65	19,264	11.97	19,264	12.07	19,264	31.36	27,393	31.30	27,255	1.00	599	1.31	362
H_2	23.68	24,455	15.19	24,455	15.32	24,455	39.70	34,678	39.82	34,678	57.46	34,504	4.37	1,207
H_2O	22.68	23,429	50.40	81,140	49.95	79,704	0.17	150	0.17	150	0.18	107	0.01	4*
CH_4	12.86	13,288	8.25	13,288	8.33	13,288	15.16	13,240	15.19	13,229	21.94	13,178	93.54	25,863
C_2H_6	0.99	1,020	0.63	1,020	0.64	1,020	1.16	1,014	1.15	1,002	1.66	998	--	--
NH_3	0.34	348	0.22	348	0.22	348	--	--	--	--	--	--	--	--
B-T-X	0.30	305	0.19	305	0.19	305	0.13	114	0.02	16	--	--	--	--
H_2S	0.19	201	0.12	201	0.13	201	0.08	71	0.08	67	--	--	--	--
N_2 + Ar	0.18	185	0.12	185	0.12	185	0.21	185	0.21	185	0.31	185	0.67	185
Total	100.00	103,288	100.00	160,999	100.00	159,563	100.00	87,359	100.00	87,087	100.00	60,048	100.00	27,649

* 7 lb $H_2O/10^6$ SCF.

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Table 4. PROCESS FLOW STREAMS FOR A NOMINAL 240 X 10^9 Btu/DAY HIGH-Btu GAS PLANT BY THE U-GAS PROCESS FROM MONTANA SUBBITUMINOUS COAL

Stream Description	Raw Gasifier Product		CO Shift Feed		Syn Gas Compressor Feed		Methanation Feed		Pipeline Gas	
Stream No.	1		2		3		4		5	
Temperature, °F	1700		376		100		25		128	
Pressure, psia	350		350		285		440		1015	
psig	335		335		270		425		1000	
Component	mol%	mol/hr	mol%	mol/hr	mol%	mol/hr	mol%	mol/hr	mol%	mol/hr
CO	34.18	43,262	19.41	43,262	14.88	19,199	21.66	19.175	0.10	29
CO_2	13.30	16,832	7.55	16,832	31.71	40,895	1.00	885	1.13	324
H_2	29.52	37,373	16.77	37,373	47.63	61,436	69.26	61,318	5.71	1,624
H_2O	17.44	22,081	53.11	118,364	0.33	429	0.43	382	0.01	4
CH_4	4.84	6,121	2.75	6,121	4.75	6,121	6.90	6,113	90.74	25,823
H_2S	0.20	248	0.11	248	0.19	248	0.1 ppmv	--	--	--
N_2 + Ar	0.52	659	0.30	659	0.51	659	0.75	659	2.31	659
Total	100.00	126,576	100.00	222,859	100.00	128,987	100.00	88,532	100.00	28,460

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The purified gas is methanated in a fixed-bed reactor where essentially all the CO and some of the CO_2 are converted by the following reactions:

$$CO + 3H_2 \rightarrow CH_4 + H_2O \qquad 5)$$

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O. \qquad 6)$$

Temperature is controlled by recycling the product so as to dilute the CO content in the feed mixtures to the four reactor stages to about 4%. This limits the maximum catalyst bed temperature to 900°F. A product gas of 961 Btu/SCF HHV leaves the plant at 1000 psig.

Water condensate from CO conversion effluent goes through oil-water separation and a Chevron waste-water treatment process. Stripped gases go to an ammonia recovery section where 69 short tons/day are recovered as by-product. Acid gases are combined with those from the hot carbonate section and sent to the Stretford unit. The by-product sulfur is 65.3 long tons/day. Total by-product B-T-X recovery is 84,144 gal/day.

SNG by U-GAS

The flow diagram for this process (Figure 2) shows major steps similar to those for the HYGAS Process. However, there are several important differences.

1. Because of the much lower operating pressure, the U-GAS system uses lockhoppers to feed the dried, ground coal to the reactor instead of slurry feed.

2. We have assumed that ammonia is not formed, and since the U-GAS reactor does not make B-T-X, recovery systems for these materials are not required.

3. The steam for CO conversion is generated by adiabatic humidification of the hot (1700°F) raw gas in the venturi scrubber, recovering heat in cooling to 380°F.

4. Because of the lower gasifier pressure compared with HYGAS (335 vs. 1165 psig), subsequent compression to 450 psig before acid-gas removal and final product compression to 1000 psig are required.

Comparison of HYGAS and U-GAS Processes for the Manufacture of Pipeline Gas

Gasifier and process parameters, process energy balances, and efficiencies for the manufacture of pipeline-quality gas by the HYGAS and U-GAS Processes are shown in Tables 5, 6, and 7. The utility requirements for each process design were estimated, and complete energy balances were made. Both plants have coal-fired boilers for steam and power generation.

The gasifier feed quantities are presented in Table 5. The U-GAS reactor consumes about 15% more coal than the HYGAS reactor at equal carbon conversions of 98%. However, the steam requirement for U-GAS is about 67% of that for HYGAS; this is because the U-GAS reactor operates at 1900°F and HYGAS has reaction zones at 1000°, 1700°, and 1850°F, so the reaction rates are higher. The most significant difference in gasifier feeds is in the amount of oxygen. The U-GAS reactor requires 7986 tons/day of oxygen, which is about 2.7 times as much as required by the HYGAS reactor. The proportionately larger U-GAS oxygen plant is one of the major factors contributing to the greater utility requirements and higher costs for U-GAS as compared with HYGAS.

Table 6 is a comparison of important process quantities for each design. The HYGAS reactor operates at over 1000 psig as compared with the 335 psig operating

Table 5. COAL, REACTOR STEAM, AND OXYGEN REQUIREMENTS FOR MANUFACTURING NOMINAL 240 X 10^9 Btu/DAY HIGH- AND LOW-Btu GAS FROM MONTANA SUBBITUMINOUS COAL

	High-Btu Gas		Low-Btu Gas
	HYGAS	U-GAS	U-GAS
Reactor Coal, lb/hr (dry)	1,039,728	1,199,943	987,553
Fuel Coal, lb/hr (dry)	232,974	335,931	105,682
Total Coal	1,272,702	1,535,874	1,093,235
Total Coal (22% moisture), tons/day	19,580	23,629	16,819
Reactor Steam, lb/hr	1,003,131	670,321	551,724
Oxygen, tons/day (98% purity)	2,999	7,986	6,573
CO-Shift Steam, lb/hr*	957,298 (Supplied by slurry vaporizer)	1,421,625 (Supplied by injecting BFW to cool U-GAS effl.)	--

* Steam going to the CO shift reactor (2/3 of total feed).

Table 6. COMPARISON OF PROCESS QUANTITIES FOR MANUFACTURING NOMINAL 240 X 10^9 Btu/DAY HIGH- AND LOW-Btu GAS FROM MONTANA SUBBITUMINOUS COAL

	High-Btu Gas		Low-Btu Gas
	HYGAS	U-GAS	U-GAS
Gasifier Pressure, psig	1,165	335	335
Gasifier Temperature, °F	1,000-1,850	1,700-1,900	1,700-1,900
CH_4 in Gasifier Effluent, mol/hr	13,288	6,121	5,038
Percent of Product Methane Made in Gasifier	51	24	100*
C_2H_6 in Gasifier Effluent, mol/hr	1,020	--	--
CO + H_2 in Gasifier Effluent, mol/hr	45,248	80,635	66,363
CO Shifted, mol/hr	10,246	24,063	--
CO_2 + H_2S + COS Removal, mol/hr	26,723	40,258	3,477
CH_4 Made in Methanator, mol/hr	12,685	19,710	--
Total CH_4 in Product Gas, mol/hr	25,863	25,823	4,931
Plant Power Required, kW	101,814	238,172	138,107
Plant Electric Motors, kW	46,602	52,523	53,196
Plant Steam or Expansion Turbine Drives, equivalent kW	55,212	185,649	4,374†
Process Cooling Water, gpm	36,610	82,662	44,572
Turbine Driver Condenser Cooling Water, gpm	29,090	113,305	--
Power Plant Cooling Water, gpm	31,810	31,265	31,225
Plant Raw Water Required, gpm	4,275	8,223	3,115
Product Gas Heating Value, 10^9 Btu/day	241.5	242.3	238.8
Product Gas Heating Value, Btu/SCF	961	937	320

* Methanation unnecessary for low-Btu gas.

† Expansion turbine.

Table 7. OVERALL ENERGY BALANCES AND PROCESS EFFICIENCIES FOR MANUFACTURING NOMINAL 240 X 10^9 Btu/DAY HIGH- AND LOW-Btu GAS FROM MONTANA SUBBITUMINOUS COAL

	High-Btu Gas		Low-Btu Gas
	HYGAS	U-GAS	U-GAS
	10^6 Btu/hr		
HHV Total Coal Input	14,368.8	17,340.0	12,342.3
Product Gas, HHV	10,061.6	10,097.6	9,953.1
	Output, % of Coal HHV		
Product Gas	70.0	58.2	80.6
By-product Chemicals	4.0	0.2	0.2
Process Vent Gases	3.0	3.0	3.1
Stack Gases	2.1	2.9	1.0
Heat Dissipated to Cooling Water and Air	17.2	31.8	10.6
Gasifier Residue	1.5	1.5	1.7
Assumed and Unaccounted Losses	2.2	2.4	2.8
Total	100.0	100.0	100.0
Overall Plant Efficiency, Coal to Products	74.0	58.4	80.8

pressure for the U-GAS reactor. Because of the higher operating pressure and the multistage hydrogasification reaction, HYGAS produces more methane in the reactor: 13,288 mol/hr of CH_4 and 1,020 mol/hr of ethane as compared with 6,121 mol/hr of methane for U-GAS. The amount of methane in the product gas is about the same (25,800 mol/hr) for both designs. However, the U-GAS reactor makes only 24% of this total as compared with 51% by the HYGAS reactor. To achieve the same total plant output of methane, a U-GAS system requires more synthesis gas, hence more oxygen, and bigger CO shift, acid-gas removal, and methanation sections. The comparable quantities of CO shifted, acid-gas removed, and methane made in the methanator for both the HYGAS and U-GAS designs are shown in Table 6.

Table 6 also indicates the substantially higher power, cooling water, and raw water requirements for the U-GAS design due to the higher oxygen usage and to the power requirement for product gas compression to 1000 psig.

Table 7 presents a comparison of overall energy balances and process efficiencies. SNG via the U-GAS Process requires about 20% more plant coal, and the coal-to-pipeline gas efficiency is 58.2% versus 70% for the HYGAS system. In addition, HYGAS has 4.0% of the feed coal HHV converted to by-products, whereas the U-GAS system has only 0.2% converted, raising the HYGAS plant efficiency. The U-GAS system has considerably more heat dissipated to cooling media: 5504 vs. 2471 million Btu/hr, or 31.8% vs. 17.2% of plant coal feed. The HYGAS system heat loss to cooling water is less than half that for the U-GAS system. This is primarily due to the very large difference in the amount of cooling necessary for the condensers on the plant turbine drivers, 84,215 gpm. The difference in process cooling, while significant, is relatively minor by comparison. Overall efficiencies (coal to all products) are 74.0% for HYGAS and 58.4% for U-GAS.

LOW-Btu GAS BY THE U-GAS PROCESS

Figure 3 shows the flow diagram for producing low-Btu gas by the U-GAS Process, an appropriate application for this process, and the process flow streams are given in Table 8. The results are more favorable than in the SNG application and are shown in Tables 5, 6, and 7. To put this plant on a comparable basis with the other plants in this study, the same product fuel value output rate was used for all three. When making low-Btu instead of high-Btu gas with the U-GAS reactor, the process coal feed is reduced to 15,193 tons/day of Montana subbituminous coal, and the plant produces 239 billion Btu/day of 320 Btu/SCF fuel gas.

For the low-Btu U-GAS reactor process, coal is dried to 10% moisture and ground to 1/4 in. X 0. Lockhoppers introduce the coal to the gasifier. Simultaneous with gasification, ash is removed from the fluidized bed by an ash-agglomerating technique, and fines elutriated from the bed returned through cyclones. The gasifier requires 551,724 lb/hr of steam and 6,573 tons/day of oxygen. Raw gas is cooled to 315°F in a waste heat boiler and is water-scrubbed in a venturi scrubber for dust removal.

Some adiabatic humidification occurs in the scrubber that cools the gas to 293°F. Prior to H_2S removal, the gas is cooled to 100°F, and the condensed water is sent to waste-water treating facilities and used as cooling tower makeup.

The hydrogen sulfide in the raw gas is removed by the Selexol Process. Besides hydrogen sulfide, a small amount of carbonyl sulfide is produced in the gasifier, and this compound is also partly removed by the Selexol Process. The total sulfur present in the clean gas is reduced to about 70 ppm. Together with hydrogen sulfide, the process removes about 24% of the carbon dioxide present in the raw gas. The H_2S-CO_2 mixture from the Selexol unit is sent to a Stretford unit where 68 long tons/day of sulfur is recovered. The clean desulfurized gas from the Selexol absorber

Table 8. PROCESS FLOW STREAMS FOR NOMINAL 240 X 10^9 Btu/DAY LOW-Btu GAS BY THE U-GAS PROCESS FROM MONTANA SUBBITUMINOUS COAL

Stream Name	Raw Gas		Scrubber Effluent		Selexol Feed		Selexol Effluent to Expander		H_2S Stream to Sulfur Recovery Unit (Stretford)		Product Gas	
Stream No.	1		2		3		4		5		6	
Temperature, °F	1700		293		100		85		115		100	
Pressure, psig	335		320		310		300		10		8	
Component	mol/hr	mol %	mol/hr	mol %	mol/hr	mol %	mol/hr	mol %	mol/hr	mol %	mol/hr	mol %
CO	35,605	34.17	35,605	33.90	35,605	41.29	35,306	43.06	299	7.04	35,306	43.06
CO_2	13,843	13.29	13,843	13.18	13,843	16.05	10,564	12.88	3,279	77.17	10,564	12.88
H_2	30,758	29.53	30,758	29.29	30,758	35.67	30,639	37.37	119	2.80	30,369	37.37
CH_4	5,038	4.84	5,038	4.80	5,038	5.84	4,931	6.01	107	2.52	4,931	6.01
H_2S	194	0.19	194	0.18	194	0.22	1	--	193	4.54	1	73 ppm
COS	10	0.01	10	0.01	10	0.01	5	0.01	5	0.12	5	
N_2 + Ar	542	0.52	542	0.52	542	0.63	539	0.66	3	0.07	539	0.66
H_2O	18,183	17.45	19,037	18.12	252	0.29	8	0.01	224	5.74	8	0.01
Total	104,173	100.00	105,027	100.00	86,242	100.00	81,993	100.00	4,249	100.00	81,993	100.00

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is heated to 700°F and then expanded in a power recovery turbine. Most of this energy (108,000 hp) is used to drive the oxygen plant air compressors, which are coupled to the expander shaft; also, 5,866 kW of electricity is generated and used to drive plant motors. The expanded gas is cooled to 100°F and sent to boilers.

COMPARISON OF HIGH-Btu (HYGAS) AND LOW-Btu (U-GAS) PROCESSES

Both the HYGAS and the U-GAS Processes provide alternative energy sources through coal conversion techniques. The process differences result because each is specifically designed for the form of energy product desired. The SNG from HYGAS is for the higher valued pipeline gas, while the low-Btu gas from U-GAS is designed for use as industrial boiler fuel for process steam generation or for combined gas turbine-steam turbine power cycles.

The U-GAS system is simpler than the HYGAS system because it requires no equipment to produce methane or remove liquid hydrocarbons. For example, the U-GAS Process does not require CO conversion, benzene recovery, methanation, or CO_2 removal (the HYGAS Process uses the hot carbonate system, which removes CO_2, and the U-GAS Process uses Selexol, which minimizes CO_2 removal).

The gasifier inputs, process quantities, energy balances, and process efficiencies are presented in Tables 5, 6, and 7 for the high- and low-Btu gas processes. Both plants have boilers for steam and/or power generation.

Table 5 presents coal, gasifier steam, and oxygen requirements. The HYGAS reactor requires 5% more coal than the U-GAS reactor, but the total coal needed, including fuel coal, is 16% more for the HYGAS Process. Fuel coal for U-GAS is less than half that for HYGAS because of the large amount of power recovered by expanding the product gas down to 10 psig. The U-GAS oxygen requirement is 6,573 tons/day, which is over twice the HYGAS requirement. This disadvantage in oxygen plant costs and utilities is more than compensated for by the much simpler product upgrading when making low-Btu gas. The HYGAS reactor requires 80% more steam than the U-GAS reactor, and HYGAS also requires about 960,000 lb/hr of CO-shift steam.

In Table 6 process quantities for the two processes are compared. Plant power required is about 38% more for the U-GAS system because of the larger oxygen plant. The HYGAS total cooling water requirement is about 29% more than for U-GAS and the raw water requirement for HYGAS is 37% more than for U-GAS. Acid-gas removal for HYGAS is 26,723 mol/hr and only 3,477 mol/hr for U-GAS. The overall plant efficiency for low-Btu gas is 80.8% compared with 74% for the high-Btu gas (HYGAS) (Table 7).

COMPARISON OF PROCESS ECONOMICS FOR COAL TO HIGH- AND LOW-Btu GAS USING HYGAS AND U-GAS PROCESSES

Capital and annual operating costs for high- and low-Btu gas processes are estimated on a comparable basis in mid-1976 dollars and are given in Tables 9 and 10. These costs do not include stack-gas cleanup because sulfur in the Montana coal is low enough to meet the emission specifications of 1.2 lb SO_2/million Btu of solid fuel burned. If the standards change in the future, stack-gas cleanup may be required. The annual operating costs and returns on investment are based on the utility financing method of the Supply-Technical Advisory Task Force — Synthetic Gas-Coal for the FPC National Gas Survey. The basic assumptions of this method are given in Table 11.

Table 9. CAPITAL INVESTMENT SUMMARY FOR NOMINAL 240×10^9 Btu/DAY HIGH- AND LOW-Btu GAS FROM MONTANA SUBBITUMINOUS COAL (Mid-1976 Costs)

Section	High-Btu Gas HYGAS	High-Btu Gas U-GAS	Low-Btu Gas U-GAS
	$\$10^6$		
Coal Storage - Reclaiming	5.0	6.0	4.3
Coal Grinding and Drying	13.7	14.3	11.8
Coal-Water Slurry Feed System (Lock Hoppers for U-GAS)	11.1	4.0	3.3
Slurry Feed Preheat (Fired Heater)	4.5	--	--
Gasifiers	43.0	22.3	18.4
Char Residue and Plant Ash Disposal	2.4	2.8	2.3
Gasifier Effluent Dust Removal System	3.8	4.5	4.0
Carbon Monoxide Conversion	11.2	10.0	--
Benzene Recovery	5.6	--	--
Prepurification (Hot K_2CO_3, Bulk, Activated Carbon, Zinc Oxide — Selexol for U-GAS Low-Btu Gas Case)	46.6	50.6	19.6
SYN Gas Compressors or Expander	--	12.0	13.7*
Methanation, Drying, and Product Gas Compression	15.2	37.3	--
Process Waste-Heat Recovery	14.2	5.1	15.7
High-Pressure Oxygen Supply	45.0	109.0	89.6
Process and Turbine Steam Generation	69.1	84.6	28.4
Turbogenerator	7.7	7.4	7.6
Electric Power Distribution	7.7	8.7	9.5
Cooling and Plant Makeup Water	4.9	8.5	3.1
Sulfur Recovery — Stretford	16.0	19.0	16.8
Waste-Water Treatment	13.1	3.0	6.5
Particulate-Emission Control	3.8	4.5	3.2
Miscellaneous	17.2	20.7	12.9
General Facilities	43.3	47.7	32.5
Installed Plant Cost, Excluding Contingencies	404.1	482.0	303.2
Contingencies at 15%	60.6	72.3	45.5
Total Bare Cost	464.7	554.3	348.7
Contractor's Overhead and Profits (15%)	69.7	83.1	52.3
Total Plant Investment (I)	534.4	637.4	401.0
Interest During Construction (9% X 1.875 years X I)	90.2	107.6	67.7
Start-up Cost (5% of Total Plant Investment)	26.7	31.9	20.1
Working Capital: 60 days' coal at full rate	10.4	12.5	8.9
0.9% of Total Plant Investment	4.8	5.7	3.7
1/24 X Annual Revenue Required	7.3	9.4	6.1
Total Capital Required	673.8	804.5	507.5

* Expander.

Table 10. ANNUAL OPERATING COSTS FOR NOMINAL
240 X 10^9 Btu/DAY HIGH- AND LOW-Btu GAS PLANTS
USING MONTANA SUBBITUMINOUS COAL
(90% Plant Service Factor — Timing: Mid-1976)

	High-Btu Gas		Low-Btu Gas
	HYGAS	U-GAS	U-GAS
Operating Cost Component		$1000	
Coal Feed, 50¢/10^6 Btu*	56,641	68,353	48,653
Catalysts, Chemicals and Other Direct Materials	3,195	5,236	847
Raw Water Cost, 45¢/1000 gal	909	1,749	670
Labor			
Process Operating Labor (for high-Btu gas, 58 men/shift for HYGAS and 60 men/shift for U-GAS; 33 men/shift for U-GAS to low-Btu gas; at $7.20/hr and 8,760 man-hr/year)	3,659	3,784	2,081
Maintenance Labor (1.5% of Total Plant Investment plus Lockhopper Maintenance Labor for U-GAS)	8,016	9,661	6,115
Supervision (15% of Operating and Maintenance Labor)	1,751	2,017	1,229
Administration and General Overhead (60% of Total Labor, Including Supervision)	8,056	9,277	5,655
Supplies			
Operating (30% of Process Operating Labor)	1,098	1,135	624
Maintenance (1.5% of Total Plant Investment plus Lockhopper Maintenance Supplies for U-GAS)	8,016	9,661	6,115
Local Taxes and Insurance (2.7% of Total Plant Investment)	14,429	17,210	10,827
Total Gross Operating Cost	105,770	128,083	82,816
By-Product Credits			
Sulfur at $10/long ton	(215)	(267)	(223)
Ammonia at $50/ton	(1,138)	--	--
Light Oil (B-T-X) at 35¢/gal	(9,674)	--	--
Total	(11,027)	(267)	(223)
Net Operating Cost	94,743	127,816	82,593
Depreciation (20 years Plant Life, Straight-Line)	32,565	38,845	24,440
Return on Rate Base	36,556	43,685	27,626
Federal Income Tax	12,052	14,402	9,107
20-Year Average Annual Revenue Required†	175,916	224,748	143,766
Annual Gas Production, 10^9 Btu	79,333	79,596	78,446
20-Year Average Gas Price, $/$10^6$ Btu†	2.22	2.82	1.83

* This is a nominal coal cost and is not to be interpreted as an IGT recommendation. Depending on mine ownership and capital charges, prices could be in the 40 to 50 ¢/10^6 Btu range. To avoid establishing a coal cost, its effect has been shown as a variable in Figure 5.

† Calculated by the Utility Financing Method (Table 11).

Table 11. GAS COST CALCULATION BY UTILITY METHOD USED IN THE "FINAL REPORT OF THE FPC SUPPLY-TECHNICAL ADVISORY TASK FORCE – SYNTHETIC GAS-COAL"

BASIS	UTILITY METHOD
Project Life	20 years
Depreciation	5%/year, straight line
Debt/Equity Ratio	75%/25%
Return on Equity	15%
Interest Rate on Debt	9%
Federal Income Tax	48%
Interest During Construction	Interest Rate (9%) X 1.875 years* X total plant investment
OTHER FACTORS	
Plant Stream Factor	90%
Contingencies	15% of installed plant cost
Contractor's Overhead and Profits	15% of total bare cost
Start-up Cost	5% of total plant investment
Working Capital	a) Coal inventory (60 days feed at full rate) b) Material and supplies (0.9% of total plant investment) c) Net receivables at 1/24 X annual revenue required

Derived equation

$$\text{20-year average gas price, } \$/10^6 \text{ Btu} = \frac{N + 0.1198\ C + 0.0198\ W}{G}$$

Where

- N = Net annual operating cost
- C = Total capital required
- W = Working capital
- G = Annual gas production

* 10% for 3 years, 90% for 1.75 years

High-Btu Gas Using HYGAS and U-GAS

The capital required for the HYGAS and the U-GAS plants for producing high-Btu gas are $674 million and $805 million (Table 9). Major items in both plants are gasification reactors, purification, oxygen supply, and offsites. The HYGAS reactor system costs more than the U-GAS reactor system because of its greater size, complexity, and the much higher operating pressure required. However, because of the much higher costs for oxygen supply, methanation, synthesis and product gas compression, and steam generation for the simpler U-GAS reactor, total capital investment for the U-GAS Process is $131 million more than for the HYGAS Process.

The calculated 20-year average gas price of $\$2.82/10^6$ Btu when a U-GAS reactor is used for SNG is substantially higher than the price of $\$2.22/10^6$ Btu for the HYGAS Process for $\$0.50/10^6$ Btu coal (Table 10). A private investor financing method (DCF) was also developed by the FPC task force comprising 100% equity capital, 25-year project life, 16-year sum-of-the-year's digits depreciation, and 12% DCF rate of return. With this method, the gas prices are $3.63 and $\$2.89/10^6$ Btu for the U-GAS and the HYGAS Processes. Use of the U-GAS reactor gives a higher price because of lower conversion efficiency and higher plant cost. This plant requires $\$11.7 \times 10^6$ more coal and produces $\$10.8 \times 10^6$ fewer by-products compared with the HYGAS plant. The by-products of 65.3 long tons/day sulfur, 69.3 tons/day ammonia, and 84,144 gal/day light oil (B-T-X) reduce the HYGAS gas price by about $\$0.14/10^6$ Btu at the unit values of $10/long ton sulfur, $50/ton ammonia, and $0.35/gal for the light oil. There are 81.4 long tons/day of sulfur by-product for U-GAS with negligible effect on gas price.

Low-Btu Gas by the U-GAS Process and Its Comparison to High-Btu Gas by the HYGAS Process

Table 9 also shows a total capital investment of $674 million for the HYGAS high-Btu plant and $508 million for the U-GAS low-Btu plant. The U-GAS oxygen supply costs $90 million, twice that for HYGAS. However, all other aspects for low-Btu gas — coal feeding, gasification, product upgrading, and offsites — cost much less.

Table 10 presents annual operating costs, 20-year average annual revenue required, and gas price. HYGAS coal costs are $8 million/year more than for low-Btu U-GAS; catalyst and chemical costs are $2.3 million/year more for HYGAS. The U-GAS system requires 25 men/shift fewer in operating labor than the HYGAS system. Capital-related costs are about $8 million more for the HYGAS system. The higher HYGAS costs are somewhat offset by the $11 million higher by-product credit. The total net difference in net operation costs is $12 million. The higher HYGAS capital and operating costs lead to a $\$0.39/10^6$ Btu higher gas price for HYGAS (HYGAS $2.22, U-GAS $\$1.83/10^6$ Btu).

If gas price is calculated using the DCF method described above, the U-GAS price is $\$2.34/10^6$ Btu compared with high-Btu gas at $\$2.89/10^6$ Btu.

Comparison of High- and Low-Btu Gas Price Sensitivities

Figure 4 shows the effect of variations in plant cost on the 20-year average gas price. The effect of variations in both installed equipment cost and total capital cost are shown. An increase of about 67% is added to the installed equipment cost by the various factors used to arrive at total capital required. For a change of $1 million in installed equipment cost, the gas price varies by $0.36¢/10^6$ Btu; for a similar change in total capital required, the gas price changes by

$0.22¢/10^6$ Btu, when the utility financing method is used. For the private investor financing method, the numbers are 0.53¢ and $0.31c/10^6$ Btu. These sensitivity factors apply to all three processes.

Figure 5 shows the effect of varying coal costs on the gas price. For high-Btu gas, the sensitivity is 1.5¢ change in gas price per 1¢ change in coal cost for the HYGAS Process. Because of the lower efficiency, the sensitivity for the U-GAS to SNG process is 1.8¢ change in gas price per 1¢ change in coal cost. The sensitivity for the U-GAS to low-Btu gas process is 1.2¢ change in gas price per 1¢ change in coal cost.

CONCLUSIONS

The manufacture of pipeline-quality gas by the HYGAS Process shows a definite advantage over its manufacture by a single-stage, lower pressure system. Although the hydrogasifier is more complex and operates at a much higher pressure than the U-GAS reactor (1165 vs. 335 psig), a much greater amount of methane is made in the HYGAS reactor. This gives large savings in coal, oxygen, and upgrading costs, resulting in a lower gas price and higher efficiency.

When a low-Btu fuel gas of low methane content is satisfactory, the simpler, low-pressure U-GAS Process shows economic and efficiency advantages.

The results are summarized below:

	High-Btu Gas		Low-Btu Gas
	HYGAS	U-GAS	U-GAS
Total capital required, $\$10^6$ (mid-1976)	674.0	805.0	508.0
Gas price, $\$/10^6$ Btu, utility financing	2.22	2.82	1.83
Overall thermal efficiency,%	74.0	58.2	80.8

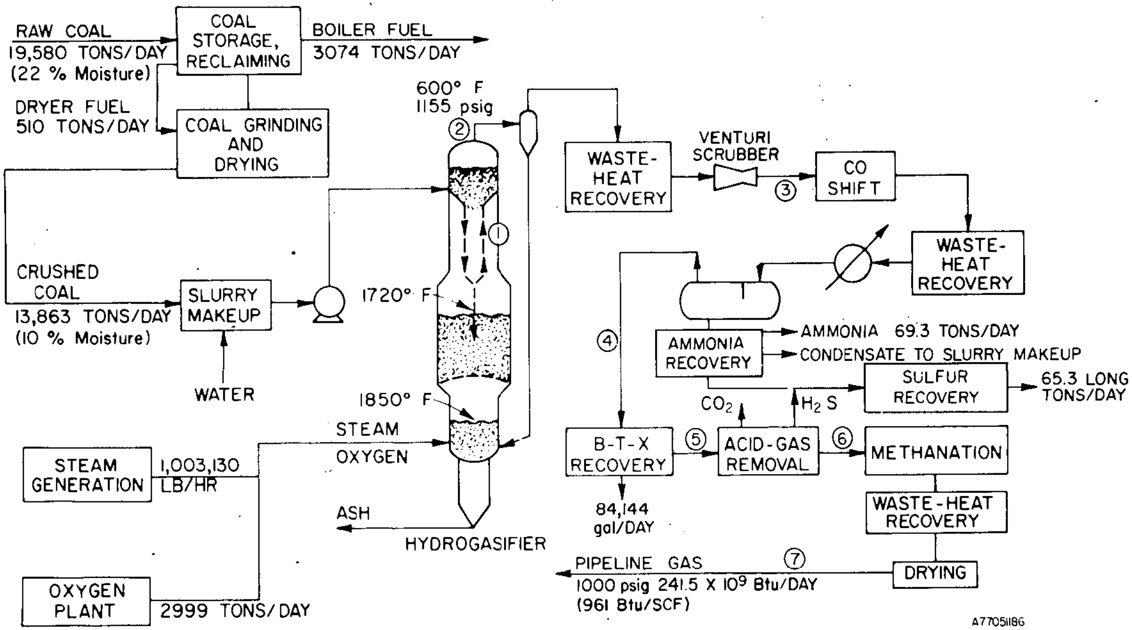

Figure 1. NOMINAL 240 X 10^9 Btu/DAY HIGH-Btu GAS BY THE HYGAS STEAM-OXYGEN PROCESS FROM MONTANA SUBBITUMINOUS COAL

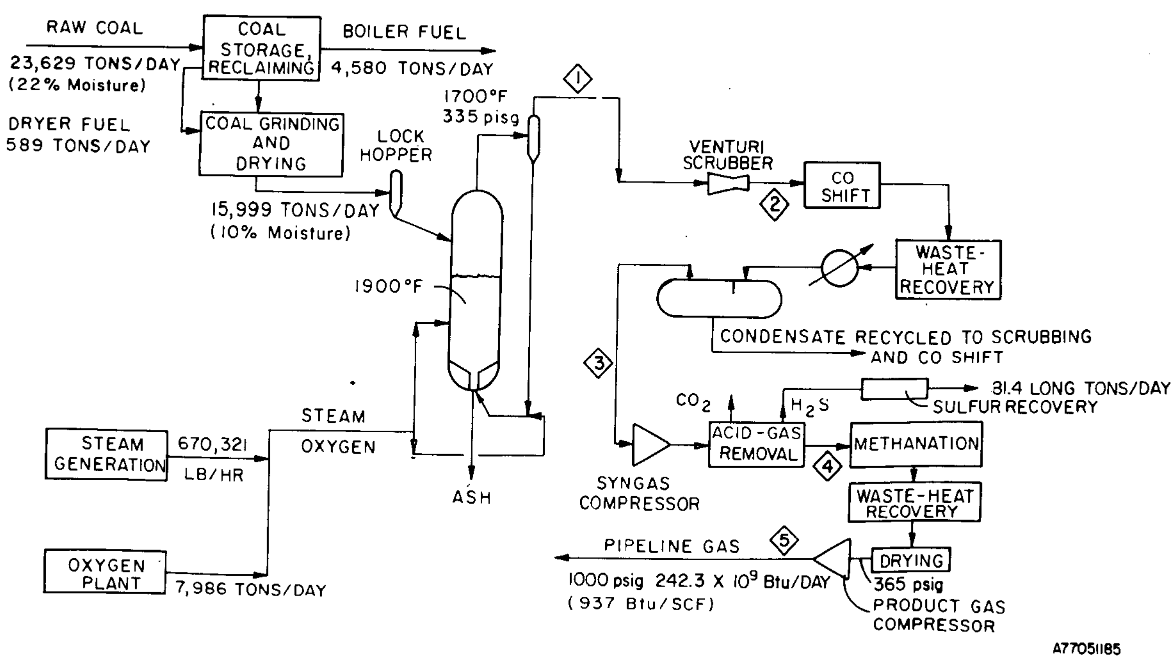

Figure 2. NOMINAL 240 X 10^9 Btu/DAY HIGH-Btu GAS BY THE U-GAS PROCESS (OXYGEN-BLOWN) FROM MONTANA SUBBITUMINOUS COAL

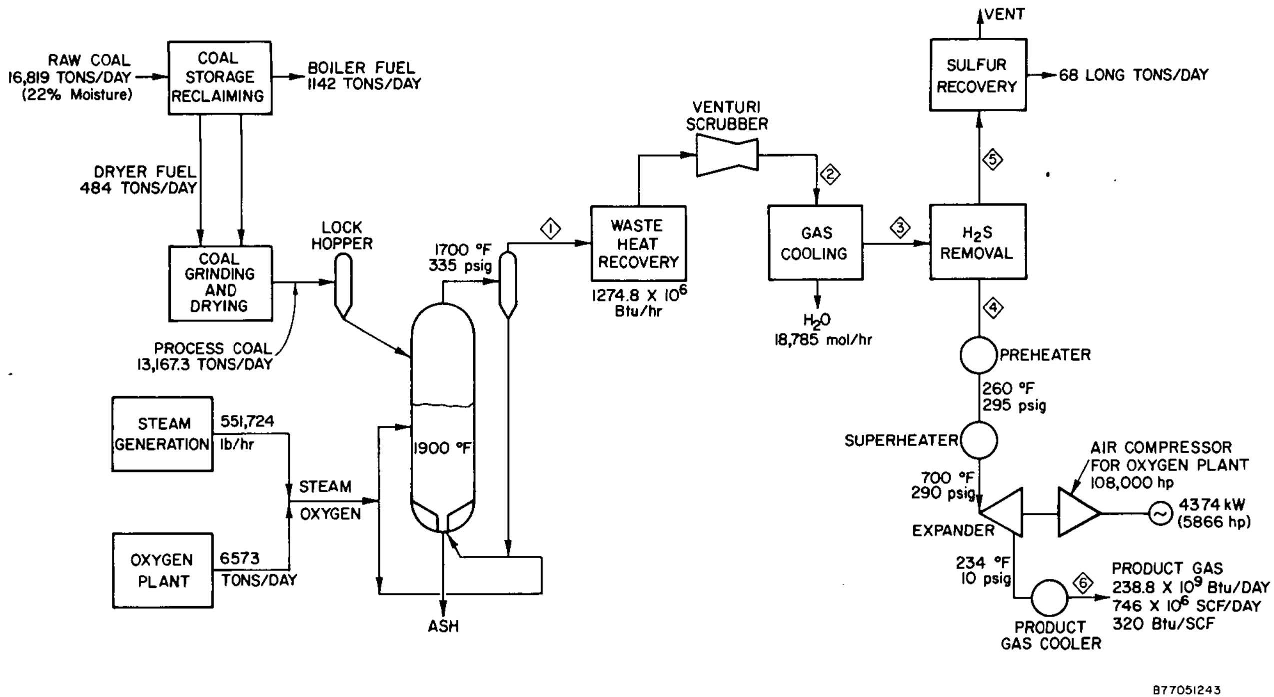

Figure 3. NOMINAL 240 X 10^9 Btu/DAY LOW-Btu GAS BY THE U-GAS PROCESS (OXYGEN-BLOWN) FROM MONTANA SUBBITUMINOUS COAL

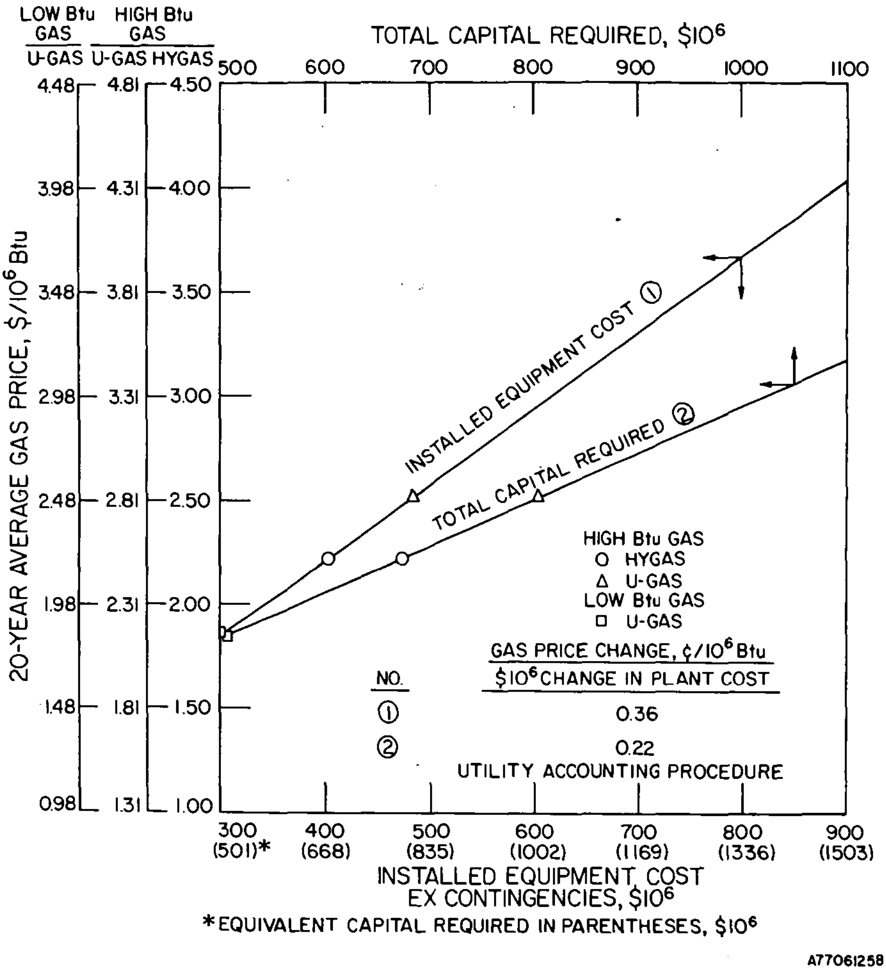

Figure 4. EFFECT OF PLANT COST ON GAS PRICE FOR HIGH- AND LOW-Btu GAS FROM MONTANA SUBBITUMINOUS COAL

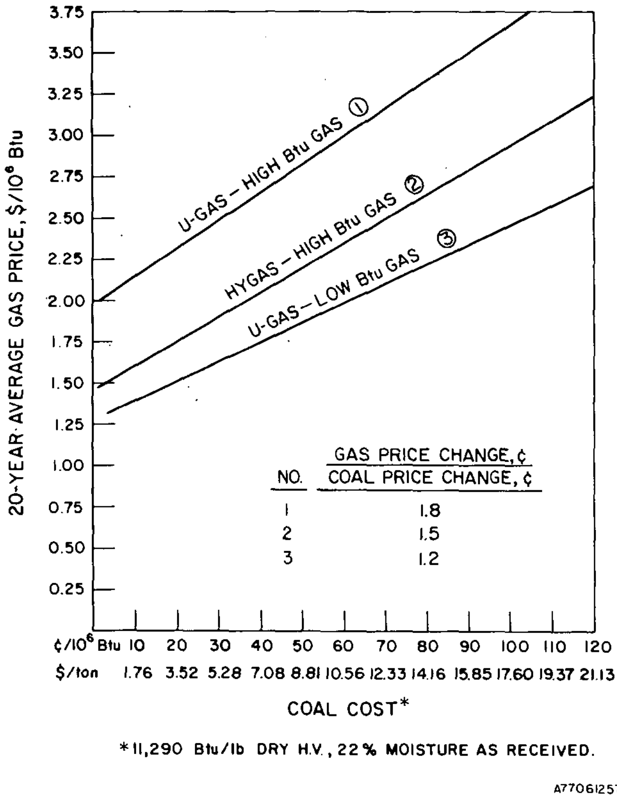

Figure 5. EFFECT OF COAL COST ON GAS PRICE FOR HIGH- AND LOW-Btu GAS FROM MONTANA SUBBITUMINOUS COAL